CONTRIBUTIONS OF SYNTHETIC RESINS TO IMPROVEMENT OF PLYWOOD PROPERTIES

A paper presented by Don Brouse, Engineer, Forest Products Laboratory,[1] Forest Service, U.S. Department of Agriculture, at a symposium on synthetic resin bonding at The Franklin Institute, Philadelphia, Pennsylvania, January 10, 1939.

Within the last 40 years, there have been four major developments in the field of woodworking glues. These may be briefly summarized as follows: First, the introduction of starch glues during the early years of this century; second, the development of casein glues on a commercial scale during the period of the World War; third, the introduction of glues from vegetable proteins during the 1920's; and fourth, the development of synthetic resins for wood bonding which has marked the most recent advance in materials available for the gluing of wood.

Synthetic resin glues promise to have a most important role in the plywood industry. Their unique properties are bringing about important changes in the manufacturing technic (1)[2] and in the quality of the plywood produced. The fact that artificial resins introduce little or no moisture into the wood during the gluing operation and the further fact that the cured resins do not soften or dissolve when brought into contact with water make it possible to produce plywood of unusual and important properties. It is to these unusual properties of the resin-bonded plywood, particularly its resistance to severe exposure conditions, that the test results presented in this paper apply.

The Forest Products Laboratory has for many years been conducting experiments to determine the durability of different woodworking adhesives with a view to providing a classification upon which a logical choice of adhesives can be made for different service requirements. When the artificial resin glues became of commercial importance, experiments were begun to evaluate the durability of these adhesives as a measure of their suitability for severe service conditions.

Previous work (2) on protein glues had shown that failure of well-made glue joints may result from one or more of three main causes: (1) Destruction by microorganisms if conditions of service favor their development; (2) chemical decomposition of the glue material itself if exposed over extended periods to sufficient moisture; and (3) mechanical action, due to the stresses of swelling and shrinking as the wood changes in moisture content. Experiments were conducted, therefore, to bring out the behavior of artificial resin glue joints when exposed to each of these different agencies of deterioration.

TEST PROCEDURE

At the time the first of these exposure tests on artificial resin glues was started by the Laboratory, the knowledge of the technic of using the artificial resin

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[1] *Maintained at Madison, Wis., in cooperation with the University of Wisconsin.*

[2] *Numbers in parentheses refer to list of references at the end of the paper.*

[N.Y., Bakelite Corp. 1938]

glues was limited largely to the manufacturers or the individuals who were developing or promoting the respective adhesives and, for the purpose of these tests, it was decided that the gluing should be done by the manufacturers rather than by the Laboratory. Yellow birch veneer (1/16 inch in thickness) selected for smoothness, firmness, straightness of grain, and freedom from defects was sent to the manufacturers with the request that they glue 20 panels, each three-ply, 3/16 by 12 by 12 inches, under those conditions of moisture content, spread, pressure, temperature, etc., that they believed most favorable for their particular product. Included in the tests were four artificial resins (P-1, P-2, P-3, and P-4) reported to be of the phenolaldehyde type and one resin (V-1) reported to be a vinyl ester.

For comparative purposes, 20 similar panels each were glued at the Forest Products Laboratory with casein and blood albumin glue. The casein glue was a casein-lime-sodium silicate combination and the blood albumin glue a paraformaldehyde-ammonium hydroxide-blood albumin combination, both described in Forest Products Laboratory publications. (3)

For the gluing done at the Laboratory, the veneer was conditioned to approximate equilibrium with 65 percent relative humidity, giving a moisture content of approximately 12 percent. The gluing with casein glue was done in the conventional way with the conditions adjusted within limits favorable to the production of good joints. The panels glued with blood albumin were spread and pressed at room temperatures, allowed to remain under pressure overnight, and then hot pressed the following morning for 10 minutes at a temperature of approximately 260° F. and under a pressure of 200 pounds per square inch.

The procedure after gluing was identical whether the panels were glued at the Laboratory or by the manufacturers. All panels were conditioned to approximate equilibrium with 65 percent relative humidity and then cut into standard plywood test specimens. The dimensions of the test specimens, the methods of test, and the testing machine are described in other publications (3). In its essentials, the test consists of cutting the plywood test specimen so that when the specimen is stressed in tension the glue joint is in shear. The load required to cause the joint to fail in shear is recorded as joint strength. The broken surfaces are examined and the area over which the failure occurred in the wood rather than in the glue joint is compared to the total area under test and recorded as percentage wood failure.

Each panel yielded 30 test specimens giving a total of 600 specimens for each glue. Five specimens from each panel were tested dry and five were tested wet after soaking in water at room temperatures for 48 hours. Any panels that gave low or erratic test values were rejected. After eliminating defective panels, the dry test values of the specimens from the remaining panels were averaged for each glue and these averages were used as a basis of comparison throughout the tests. The same procedure was carried out to obtain the wet test values, although these were not used as a base for comparison. For each glue, the specimens were then mixed together to insure random sampling and divided into four groups of 75 specimens each, one group for each of the following exposures:

1. Continuous soaking in water at room temperatures.

2. Continuous exposure to 97 percent relative humidity at 80° F.

3. Exposure to a repeating cycle consisting of 2 days soaking in water at room temperatures followed immediately by drying for 12 days at 80° F. and 30 percent relative humidity.

4. Exposure to a repeating cycle consisting of 2 weeks in 97 percent relative humidity at 80° F. and 2 weeks in 30 percent relative humidity at 80° F.

From each group, five specimens were tested at intervals of 2.5, 5, 8, 12, 18, 24, 30, 36, 42, and 48 months. For cyclic exposures nos. 3 and 4, the testing was done at the end of the dry period of the cycle. Specimens from exposure no. 1 were tested wet as soon as possible after removal from soaking and specimens from exposure no. 2 were tested promptly upon removal from 97 percent relative humidity. The test values for each group of five specimens were averaged and the averages are shown in table 1. Since an insufficient number of specimens glued with resin P-2 was available for all the tests, this glue was included only in the soaking-drying tests. Its omission from the other tests necessitated two sets of "control" averages in column 6 of the table.

The tests are still in progress (Dec. 1938) with sufficient specimens remaining to continue the study through the 60th month.

Since the phenolic resin glues behaved similarly, the results were averaged (column 6, table 1) and these average values were used in preparing the charts rather than showing each individual resin separately. All successive average strength values, further, were plotted as percentages of the original average values from the dry tests. This procedure permitted easier comparison of the rates of failure since all lines start from the same origin of 100. The wood failure, of course, was originally recorded as a percentage and required no recalculation.

In these tests, the specimens were unprotected, the dimensions were small, and the specimens spaced on rods to permit circulation of water or air during the exposure cycles. The wood, therefore, probably attained approximate equilibrium with the exposure conditions at each period of the exposure cycle and the stresses developed on the glue joints approached the maximum that could be expected under the conditions prevailing.

RESULTS

One of the first impressions gained in this study was the importance of the amount of wood failure developed when testing the joints. With the casein glues, the percentage of wood failure was low after any appreciable exposure to moisture. With many of the artificial resin glues, however, the amount of wood failure developed usually exceeded 50 percent and often approached 100 percent. For this reason it is important to include wood failure values in tables and charts if an accurate picture of the quality of joint is to be presented. When the percentage of wood failure developed in a test approached 100, obviously the strength of the wood in shear rather than the strength of the bond, determined the strength test value obtained.

TEST NO. 1. CONTINUOUS SOAKING IN WATER. The wet test values (second row, table 1) indicate primarily the degree to which the joints are weakened by early softening of the glue, particularly if low strength values are combined with low wood failure. When long continued, however, soaking in water serves as an approximate measure of the rate or the degree to which the joints weaken by the hydrolysis of the glue itself.

Conforming to results of previous experiments, the casein glue hydrolyzed at such a rate that all the joints had failed completely at the end of 25 months and at the end of 18 months the average test value was nearly down to zero.

As might be expected from a consideration of their chemical composition, the artificial resin glues used in these tests did not show a tendency to weaken when soaked continuously in water. If that tendency was present at all, it was masked by the more rapid weakening of the wood itself. When the average figures are plotted (figure 1) they show a gradual decrease in strength but the average percentage of wood failure at the end of four years is some 72 percent, an amount approximately equal to the average wood failure developed in the original dry tests. The vinyl resin is not included in the averages plotted on the chart but, like the other artificial resins in this respect, it did not appear to weaken any more rapidly than the wood when soaked continuously in water.

The artificial resin glues, however, are not alone in their ability to resist exposures of this type. The paraformaldeyhde-blood albumin glue applied by the hot pressing method does not hydrolyze at all rapidly. So far as resistance to continuous soaking is concerned, specimens glued with hot-pressed, paraformaldehyde-blood glue performed as well as the specimens glued with synthetic resins.

TEST NO. 2. CONTINUOUS EXPOSURE TO 97 PERCENT RELATIVE HUMIDITY. The conditions of this exposure are favorable to the development of fungi. Under these conditions, molds attack an unprotected protein glue rapidly and wood destroying fungi cause rotting of nondurable and unprotected wood.

The casein glue used contained no chemical of sufficient toxicity to retard mold growth and the joints made with this glue failed rapidly, dropping to 19 percent of their original strength after 2.5 months (fig. 2). All specimens glued with casein glue had failed completely by the end of the 12th month.

The artificial resin glues of the phenolic type appear to be resistant to attack by microorganisms. The strength test values decreased slowly but the percentage of wood failure increased, indicating that the wood was failing more rapidly than the glue, and not establishing clearly whether the glue itself had been weakened. At the end of 18 months, visual evidence of rotting could be detected in specimens glued with phenolic resins and by 36 to 48 months the wood had rotted to a very marked degree. While the phenolic glues themselves were apparently not attacked by microorganisms, the presence of a phenolic glue line did not afford protection sufficient to prevent wood rot in three-ply, 3/16-inch birch plywood.

The resistance of vinyl resin joints was not clearly established by these tests. At the end of 48 months, the test values had decreased to some 55 percent of their original value. The specimens were clearly rotted but the percentage of wood failure did not increase to the extent that might have been expected from the amount of rot present.

Against mold action, the resistance of the hot pressed paraformaldehyde-blood glue appeared to be more than equal to the resistance of yellow birch to wood destroying fungi. The fact that 100 percent wood failure was developed in all tests of blood glue joints in this exposure at the fifth month and thereafter indicated that the decrease in test values was due to a weakening of the wood rather than failure in the glue itself. In tests of this type, additional information might have been gained if tests had also been carried out with a more durable species of wood, such as the heartwood of southern cypress, redwood, or western red cedar.

Two conclusions from this test should be emphasized:

1. The resistance of phenolic resins to attack by microorganisms appeared

to be entirely satisfactory but not greater than that of hot-pressed blood glues that contained paraformaldehyde.

2. The presence of a glue line resistant to fungi did not prevent rotting of the wood. The production of plywood resistant to this type of exposure requires a glue resistant to fungi and a species of wood resistant to wood destroyers, or a treatment of the wood with effective preservatives.

TEST NO. 3. EXPOSURE TO A REPEATING CYCLE THAT CONSISTED OF SOAKING IN WATER FOR 2 DAYS FOLLOWED BY DRYING FOR 12 DAYS IN 30 PERCENT RELATIVE HUMIDITY. This exposure, which approached most nearly to exterior conditions, was one that brought out most clearly the superiority of the hot-pressed phenolic resin glues over all the other glues used in these experiments. The casein glue joints lost something over 40 percent of their strength during the first test period of 2.5 months (figure 3) and had failed almost completely at the end of 18 months.

At the end of 4 years, joints made with paraformaldehyde blood glue still retained something over 20 percent of their original dry strength but the test values showed in general a steady and consistent decrease. The average percentage of wood failure never exceeded 44 percent and, after the 18th month, no wood failure could be detected by visual inspection of the broken specimens. The trend at the 48th month indicated that the blood-glue joints were approaching ultimate failure. Similar tests, carried out previously on blood-albumin joints results in total failure at from 25 to 30 months (4).

On the other hand, joints made with phenolic resins have retained an average of 60 percent of their original dry strength through 4 years of alternate soaking and drying. More important, the average percentage of wood failure in the 4-year specimens was some 53 percent. The average test values appeared to be decreasing but the fact that a high percentage of wood failure continued to be developed indicated that the severe exposure may have been weakening the wood. At the 48th month there was no positive indication that the joints would fail more rapidly than the wood itself although the wood failures seem to be trending downward slightly.

In this very severe exposure, the vinyl ester glue line (table 1) appeared to lack the necessary strength when wet and the joints weakened at a rate approximating that for casein glue joints. The results of the soaking-drying cycle are in harmony with the test values obtained after soaking the specimens in water for 48 hours (2nd row, column 7, table 1). The wet test values are only some 68 percent of the dry test values while for the phenolic resins the wet test value was some 95 percent of the dry test value.

TEST NO. 4. EXPOSURE TO A REPEATING CYCLE OF 2 WEEKS EXPOSURE TO 97 PERCENT RELATIVE HUMIDITY FOLLOWED BY 2 WEEKS EXPOSURE TO 30 PERCENT RELATIVE HUMIDITY. From the nature and rate of failure it appears that the primary cause of failure in this test cycle was attack by microorganisms. The casein joints failed more rapidly than they did in the soaking-drying test (table 1) yet it was improbable that the mechanical stresses involved were more severe. The exposure serves to illustrate probable performance of unprotected joints with the different glues exposed in service to dampness and warmth for a period followed by a period of dryness.

As in tests involving continuous exposure to high humidity, the resistance of paraformaldehyde blood glue was satisfactory. At the end of 4 years the average test value was some 68 percent of the original dry-test value and the percentage of

wood failure was over 50 percent (fig. 4). Slight evidence of wood rot could be detected by visual inspection, indicating that the decrease in test values was due, at least in part, to a loss of mechanical strength of the wood.

As might have been expected from their behavior in other tests, phenolic resin joints were not seriously affected by this exposure. A relatively high percentage of wood failure was developed at each test throughout the 4 years. Whatever the decrease in average test values, it appeared to be due to a decrease in the strength of the wood rather than weakness in the glue. Visible signs of wood rot could be detected in some of the specimens, indicating again that a glue line resistant to fungi does not offer sufficient protection to the wood against attack by wood destoyers.

The joints made with the vinyl ester did not appear to be affected by mold and they withstood this exposure much better than they did the soaking and drying cycles.

SUMMARY OF LABORATORY EXPOSURE TESTS

Joints made with different artificial resin glues of the phenolic type have satisfactorily withstood four years of exposure to extremely severe test conditions. These glues did not appear to soften or to hydrolyze on continuous soaking in water and the joints were not affected by molds, although the presence of the mold resistant glue line did not protect the wood itself from the action of wood-destroying fungi. After 4 years of soaking and drying the specimens still developed a high percentage of wood failure in test.

It appears from these results that there is available a glue bond that, when properly made, will remain intact under service conditions as severe as the wood itself will withstand. One of the first reactions to such a development is that here is a method by which plywood suitable for the structural uses may be produced. But in the past, many promising markets have been destroyed by the introduction of materials either unsuited for the purpose or before they were sufficiently developed. To reduce the chances of the potential market for highly resistant plywood being destroyed by products unsuitable for the purpose, rigid specifications are desirable that will tend to prevent the promotion of grades of plywood unsuitable for the intended service.

EXTERIOR EXPOSURE TESTS

When it became apparent that resin bonded plywood was to become of commercial importance, therefore, the Forest Products Laboratory began a series of "weathering tests" designed to determine (1) how plywood glued with the different water resistant glues, with different species, with different thickness combinations, and protected by different coatings withstands prolonged exposure to the weather, and (2) whether any correlation could be found between behavior on prolonged exposure to weather and short term laboratory tests that could be included as a part of specifications.

The weather test panels were glued 24 inches square. After conditioning to approximate equilibrium with 65 percent relative humidity, they were trimmed to 18 by 18 inches in size and then fastened to a frame fence facing south, for continuous exposure to the weather. The trimmings from the panels were cut into conventional

plywood test specimens. Of the specimens from each panel, 5 were tested dry, 5 were tested wet after soaking in water at room temperatures for 48 hours, 5 were tested dry after being exposed 3 times to a cycle that consisted of boiling in water for 2 days followed by drying at 212° F. for 2 days, 5 were tested dry after a similar exposure to a cycle consisting of soaking in water at approximately 150° F. for 2 days followed by drying at 150° F. for 2 days, and 5 were tested wet after 3-1/2 exposures to a cycle consisting of 24 hours soaking in water at room temperatures followed by drying at approximately 150° F.

In addition to the foregoing, 20 specimens from each panel were reserved for a longer test that consisted of soaking in water at room temperatures for 2 days followed by drying for 12 days at 80° F. and 30 percent relative humidity. From the results it was hoped that a correlation might develop between behavior of plywood exposed unprotected to the weather and behavior of plywood specimens in controlled laboratory tests.

The weathering exposures started in September and October, 1936. Now, after the tests have been in progress for 2 years, some preliminary remarks can be made as to the condition of the uncoated panels and the possibilities of correlation with results of laboratory tests on the trimmings. The remarks are limited to the panels that were exposed without surface or edge protection of any kind. The glue joints in the panels that were effectively protected are, of course, in good condition but, in such cases, the test is one of the effectiveness of the protection rather than a test of the durability of the glue joint.

Of the 258 panels that were glued with artificial resins (both the urea and the phenol type are grouped together for this comparison) and exposed unprotected, 121 (47 percent) show no signs of glue joint failure that can be detected by visual inspection of the panels; in 106 (41 percent) of the panels a slight opening of the glue joints along the edges or corners can be detected but the amount of failure is not considered great enough to affect the serviceableness of the panel; 31 of the resin-bonded panels have failed in the joint to a degree where the serviceableness and structural strength of the panel might be questioned, but no resin-bonded panel thus far has failed completely (fig. 5).

Of the 186 panels glued with casein glue and exposed without protection, 41 panels (22 percent) have failed completely in the 2 years exposure to the weather, 131 panels (70 percent) have failed in the glue lines to a marked degree, only 14 panels show slight failure in the glue joints, and no panel glued with casein glue came through the 2 years of weathering with no failure in the glue joint (fig. 5). Of the 14 panels that have thus far developed only slight failure, most of them were of species, such as redwood, western red cedar, and Port Orford cedar, that are low in density and that contain extractives that probably restrain the development of fungi. Even though all these panels were exposed in the open and completely out of contact with the ground, mold attack evidently has been a factor in causing failure of the casein joints. Failures from mechanical stresses appeared to proceed gradually and at a comparatively slow rate of speed but when molds develop the failures may be complete and comparatively rapid. In most of the casein glued panels that have failed completely, there was distinct evidence of mold attack while the casein glued panels classified as showing "marked failure" (figure 5) seem to illustrate the more gradual progress of a failure due to mechanical stresses.

The number of panels glued with blood albumin glue was too small to afford a good comparison with those glued with synthetic resins or with casein. Of the 12 panels glued with blood albumin, 9 have failed slightly in the glue line and 3 have failed to a marked degree. As might have been predicted from laboratory tests, they

appeared to withstand weathering better than the casein glued panels but not so well as those glued with synthetic resins.

In considering the panels glued with soybean glues, there was again the limitation of the small number of panels and, in addition, the fact that the soybean glue used was not of a type recommended for use on hardwoods. In general, however, the results conform to expectation from laboratory tests. Of the 12 panels, 6 have failed completely, 5 have failed to a marked degree, and 1 shows only slight evidence of failure.

While the different types of resins were not separated in preparing figure 5, the panels that were glued with phenolic resins are thus far in somewhat better condition than those that were glued with the urea resins. Further, the panels glued with urea resins applied by the hot process are in somewhat better condition than those glued with urea resins by the cold process.

This information is interesting in itself for it demonstrates that properly designed panels can be glued even with the denser species that, without paint or other protection, will withstand at least 2 years of actual weathering without glue-line failure. It is of greater interest, however, to examine the results of the laboratory tests made on the trimmings of these panels to see whether or not a prediction might have been made of the behavior of the panels in the weathering tests.

Strength test values do not yield the desired information because the design of the conventional plywood test specimen and the method of test cause variations in test values that depend on thickness and species of wood rather than on strength of the glue bond alone.

Wood failure, however, is not dependent on thickness combinations. It is dependent upon wood species in that a glue joint of a certain inherent strength would, upon test, break more fibers of a weak, low density wood than of a strong, high density species. In other words, it will require better glue and gluing technic to produce upon test a high percentage of wood failure in a strong species than in a weak species. Thus a high percentage of wood failure, irrespective of species and joint strength, indicates that the glue line was able to withstand any of the stresses placed on it by the wood from the time of gluing up to the time of testing. If, in the interval between gluing and testing, the specimens are subjected to rapid moisture changes from oven dry to above the fiber saturation point, the glue line will undergo the maximum stresses that can be placed on it by the shrinking and swelling of the wood. If this moisture change from dry to wet and back again to dry is repeated several times, the glue line will be subjected to the stresses set up by drying when the glue is wet and softened (if such are the characteristics of the glue) from the soaking. It appears that a wetting and drying cycle should serve as a measure of the resistance of the glue line to any stresses that can be set up by the wood in its attempts to change dimensions, and that the cycles can be arranged to produce these stresses when the glue is in its weakest condition. The development of a high degree of wood failure on test after a soaking and drying cycle should indicate, therefore, that the glue can withstand any stresses that the wood itself can exert.

A comparison of the results of tests on the plywood specimens with the results of the weathering tests at the end of 2 years confirms these ideas particularly well in the group of resin-bonded panels.

Plywood-test specimens from the group of resin-bonded panels that showed no signs of joint failure at the end of the second year of weathering averaged 78 percent wood failure (figure 5) when tested wet after 3-1/2 exposures to a cycle that

consisted of soaking in water at room temperatures for 24 hours followed by drying for 24 hours at 150° F. Specimens from the resin-bonded panels that had failed but slightly in the weathering test showed an average of 55 percent wood failure when tested wet after exposure to the cycle described. Specimens from the panels that failed to a marked degree when exposed to the weather showed an average of but 6 percent wood failure after exposure to the cyclic test. It appears, therefore, that by the use of a cyclic test and a proper selection of the amount of wood failure, it would have been possible to eliminate most of the panels that are not showing satisfactory service in the first 2 years of the weathering test.

Judging from their condition at the end of the second year, it is obvious that the unprotected casein glued panels lack the degree of resistance necessary to withstand prolonged exposure to the weather. The specimens from these panels showed only a minor degree of wood failure when subjected to the cyclic test and their behavior in the weathering test has not been satisfactory.

The same remarks apply to the panels glued with soybean glue. The glue lines have not been sufficiently resistant to withstand prolonged exposure to the weather and this was predicted by the small amount of wood failure developed upon test after a short cyclic exposure. The panels glued with blood glue (Forest Products Laboratory paraformaldehyde formula, hot-pressed) have withstood the weathering test better than the panels glued with casein or with soybean glues. From the condition of the weathering panels after 2 years, however, it seems that ultimate failure of the blood glue lines will result and that the glue used in these tests, while ranking next to the artificial resins in its resistance to weathering, was not sufficiently resistant for unprotected exterior service.

From the results at the end of the second year, therefore, it seems that only those panels that are well-bonded with artificial resin glues should be considered for the more severe service conditions. From figure 5, it appears that, if plywood specimens show 50 percent or more wood failure after undergoing a wetting-drying cycle, the plywood from which the specimens were taken may be expected to have high resistance to weathering conditions.

No claim for high accuracy can be made for this testing procedure. However, so far as our work has gone up to the present time, this correlation between wood failure after a cyclic exposure and behavior when exposed unprotected to the weather has been closer than any other with which we are familiar. It is to be noted, of course, that the weather exposure tests have been under way for only 2 years and in a northern climate. They do not show how long the resin-bonded plywood will last under these conditions or whether it would fail more rapidly in a wetter and warmer climate.

GENERAL

When the National Bureau of Standards was promoting the development of plywood specifications, the cyclic test was suggested as a basis for the requirement to be established for plywood to be used out of doors or under conditions of severe exposure. Up to the present time, no general specifications for plywood have been established but the Douglas Fir Plywood Association, acting in cooperation with the National Bureau of Standards, has adopted Commercial Standard CS45-38 that contains the following provisions for "exterior" plywood:

".....Five samples shall be cut as shown in figure 1 from each test piece.

They shall be submerged in water at room temperature for a period of 48 hours and dried for 8 hours at a temperature of 145° F. (± 5° F.) and then followed by two cycles of soaking for 16 hours and drying for 8 hours after the conditions described above. The samples shall again be soaked for a period of 8 hours and tested while wet......... The test specimens must show no less than 30 percent minimum and 60 percent average wood failure, and no delamination....."

The problems connected with the use of plywood as a structural material, however, do not end with the production of a sound and durable glue joint. For many uses, face checking is a serious defect and, while some species may face check more readily than others, it is a characteristic that must be considered with all species. Careful attention to the details in the manufacturing process, such as proper treatment of logs preparatory to cutting, proper cutting and drying of the veneer, careful control of gluing procedure and proper conditioning and storage of the plywood, as well as the use of protective coatings, reduce tendencies to face check. However, so long as wood retains its characteristics of swelling in a damp atmosphere and shrinking in a dry atmosphere face checking may be expected when moisture changes become sufficiently marked.

The Forest Products Laboratory has for some time been investigating the possibilities of minimizing the swelling and shrinking of wood by treatments that are aimed at replacing the water in the minute cellular structure of the wood with a material that would remain in place and prevent or reduce further dimension changes. In a paper presented at the September 1938, meeting of the Division of Colloid Chemistry, American Chemical Society, (Milwaukee, Wisconsin, September 5-9, 1938), Stamm and Seborg reported that "phenol-formaldehyde-catalyst intermediates that are but slightly polymerized and are soluble in water have been found to meet the requirements and to give the greatest and most permanent reduction in swelling and shrinking." Anti-shrink efficiencies (the reduction in shrinkage caused by the treatment divided by the shrinkage of the control) approaching 60 percent are reported for specimens containing some 40 percent of resin (based on dry weight of the untreated wood). In 6 months exposure to weather, unprotected panels with faces treated by this method have shown much less face checking than untreated controls. Limited experiments indicate that this treatment may be of decided value in preventing face checking of highly figured face veneers. In addition to reducing face checking, the treatment improves certain other properties. The rate of moisture transfusion, for example, is reduced, the resistance to decay is increased, and the hardness and compressive strengths are increased. The cost of materials for the treatment is estimated at about one cent per square foot, based on 1/16-inch birch of average density. It is too early to predict what difficulties and objections may be encountered in attempting to use this method on a commercial basis, but, at the present time, it appears that resins may have a place in reducing the undesirable characteristic of wood to change dimensions with moisture changes.

Another objection that is often raised to the use of wood in general is that of the fire hazard. While competitive materials have probably capitalized on this hazard more than the facts would justify, there is an entirely justifiable demand for proper precautions. One method of modifying the hazard is to treat the wood with chemicals that will prevent the wood from supporting its own combination. Plywood glued with water resistant glues can be treated with these fire-retardant salts after gluing but the treatment would be somewhat simpler if the veneers could be treated before gluing. Unfortunately many of the salts that are commonly used to impart fire-retardant properties interfere with gluing when the common aqueous glues are employed. These salts, however, interfere less with the synthetic resins than with aqueous suspensions of the proteins. Hence the artificial resin glues appear to offer a means for gluing treated material that could not heretofore be glued on a

commercial basis.

Glue lines of the phenolic types of artificial resins offer a further advantage in reducing fire hazard in the use of plywood. When plywood is subjected to flame the performance depends partly on the properties of the glue line. If the glue line is destroyed by comparatively low temperatures or loses its adhesive properties as soon as the wood begins to char, the results will not be so favorable as when the glue withstands higher temperatures and maintains a degree of adhesion after the wood begins to char. In fire tests on phenolic resin-bonded plywood, the charred plies of wood hold together while the other glues, that so far have been tested at the Forest Products Laboratory, the adhesive qualities are lost as soon as the wood begins to char and the plies separate promptly, continually exposing new plies to the flame.

In general, the artificial resins appear to offer the possibility of producing plywood possessing properties that are marked improvements over anything that has been heretofore available. If the quality of the product is properly maintained and guarded, new uses for this highly resistant plywood should continue to develop as the public becomes convinced that it has reliable sources of durable plywood.

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Table 1. - A summary of average test values obtained upon subjecting specimens of birch plywood to different conditions of exposure.

Time of exposure \ Glue	Resin P-1	Resin P-2	Resin P-3	Resin P-4	Average of P-1, 2, 3 and 4	Resin V-1	Blood	Casein
Test Values[1]								
None Dry controls	473-77	435-100	590-74	479-86	(514-79[2]) (494-84[3])	404-27	447-48	418-5
48 hrs. Wet[4]	460-73	329-92	443-67	375-65	(426-68[2]) (402-74[3])	275-5	379-51	265-2
Soaked continuously in water								
2-1/2 months	398-90		456-62	350-44	401-65	246-6	368-28	196-0
5 "	421-100		412-74	375-75	402-83	239-8	344-26	151-0
8 "	327-69		387-60	352-14	355-48	214-2	341-31	126-2
12 "	396-73		399-22	301-58	365-51	251-38	305-82	49-0
18 "	399-100		332-90	331-45	354-78	223-52	305-74	8-0
24 "	278-67		284-34	243-46	268-49	183-24	307-66	0-0
30 "	304-72		277-70	278-31	286-58	189-20	238-62	0(25)
36 "	291-100		268-58	242-68	267-75	179-42	232-90	
42 "	233-98		228-100	242-86	234-95	154-64	241-100	
48 "	231-94		229-73	157-48	206-72	117-64	211-93	
Exposed continuously to 97% relative humidity								
2-1/2 months	356-45		414-96	360-65	377-69	277-5	397-90	81-6
5 "	450-98		464-100	354-60	423-86	263-12	340-100	0-0
8 "	328-99		463-100	342-44	378-81	223-0	295-100	0-0
12 "	335-80		477-98	332-63	381-80	301-33[5]	251-100	0(12)
18 "	423-100[5]		446-100[5]	294-62[5]	387-87	262-40	256-100[5]	
24 "	339-73		448-100	290-33	359-69	258-22	215-100	
30 "	319-100		372-82	242-99	311-94	234-2	158-100	
36 "	340-100		434-89	275-100	350-96	245-42[6]	162-100[6]	
42 "	212-100[6]		382-98	194-90[6]	263-96	237-18	131-100	
48 "	353-100		326-100[6]	180-100	286-100	223-37	91-100	
Exposed to a repeating cycle: 2 days soaking followed by 12 days drying in 30% relative humidity.								
2-1/2 months	477-97	346-99	448-24	412-100	421-80	211-1	328-20	237-0
5 "	429-74	397-98	487-32	411-46	431-63	90-2	397-0	204-0
8 "	524-89	427-72	512-83	433-32	474-69	130-28	407-29	93-0
12 "	495-60	382-99	483-47	351-61	428-67	58-0	298-0	43-0
18 "	493-76	402-80	427-82	400-46	431-71	28-0	323-40	0-0
24 "	438-92	362-46	446-49	437-78	421-66	0(19)	233-0	42-0
30 "	476-66	394-36	468-54	273-10	403-42		270-0	0(25)
36 "	348-99	279-80	312-68	205-14	286-65		129-0	
42 "	392-46	370-78	490-20	198-3	362-37		135-0	
48 "	345-28	291-65	368-91	187-28	298-53		105-0	
Exposed to a repeating cycle: 2 weeks in 97% relative humidity followed by 2 weeks in 30% relative humidity.								
2-1/2 months	577-77		553-70	395-47	508-65	270-5	383-56	267-2
5 "	497-93		530-86	370-14	466-64	250-4	356-99	251-0
8 "	465-89		451-79	367-8	428-59	204-2	356-98	50-2
12 "	530-92		512-46	408-66	483-68	162-11	332-36	0(12)
18 "	420-94		465-98	372-28	419-73	226-8	359-82	
24 "	401-56		466-71	346-21	404-49	52-0	330-73	
30 "	541-77		489-59	354-22	461-53	64-10	314-30	
36 "	420-88		520-95	306-15	415-66	77-2[5]	279-59	
42 "	537-70		453-41	344-31	445-47	120-8	292-34	
48 "	393-100[5]		489-89[5]	268-0[5]	387-63	92-6	305-57[5]	

[1] First figure in each pair of values is joint strength in pounds per square inch; the second figure is wood failure in percent. Each value is an average of 5 specimens. Figure in parenthesis represents time in months when last specimen failed.

[2] Averages of P-1, 3 and 4.

[3] Averages of P-1, 2, 3, and 4.

[4] Tested wet after soaking in water at room temperature for 48 hours.

[5] Slight evidence of wood rot.

[6] Marked evidence of wood rot.

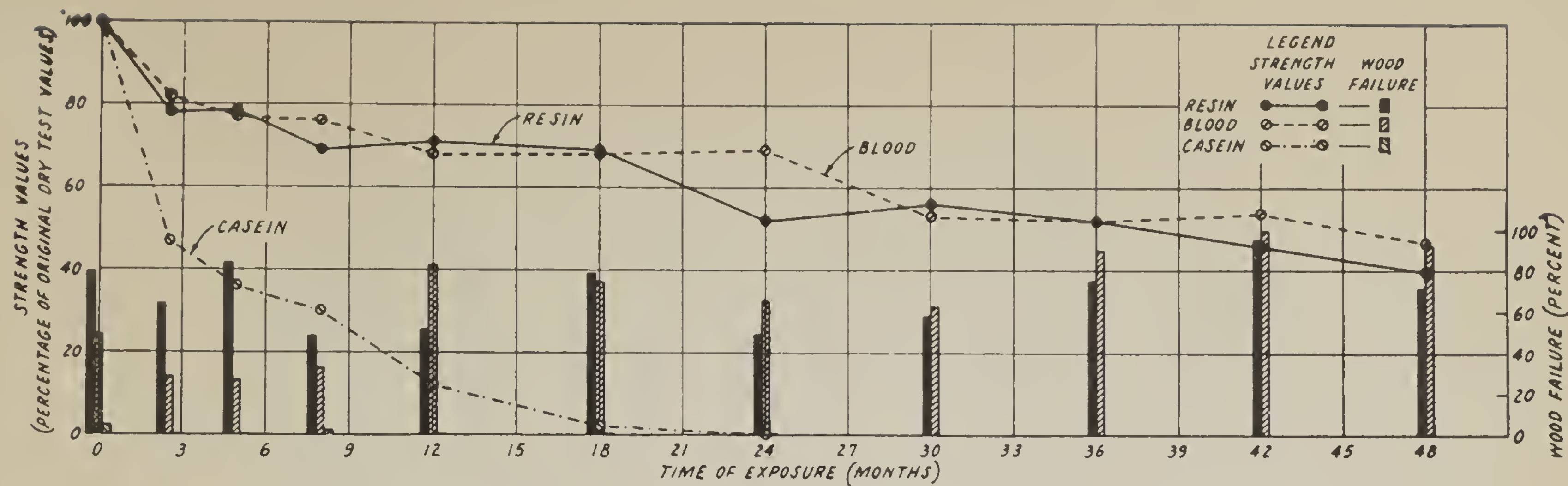


FIG. 1 RATE OF DETERIORATION OF GLUE JOINTS WHEN SOAKED CONTINUOUSLY IN WATER

FIG. 2 RATE OF DETERIORATION OF GLUE JOINTS WHEN EXPOSED CONTINUOUSLY TO 97 PER CENT RELATIVE HUMIDITY

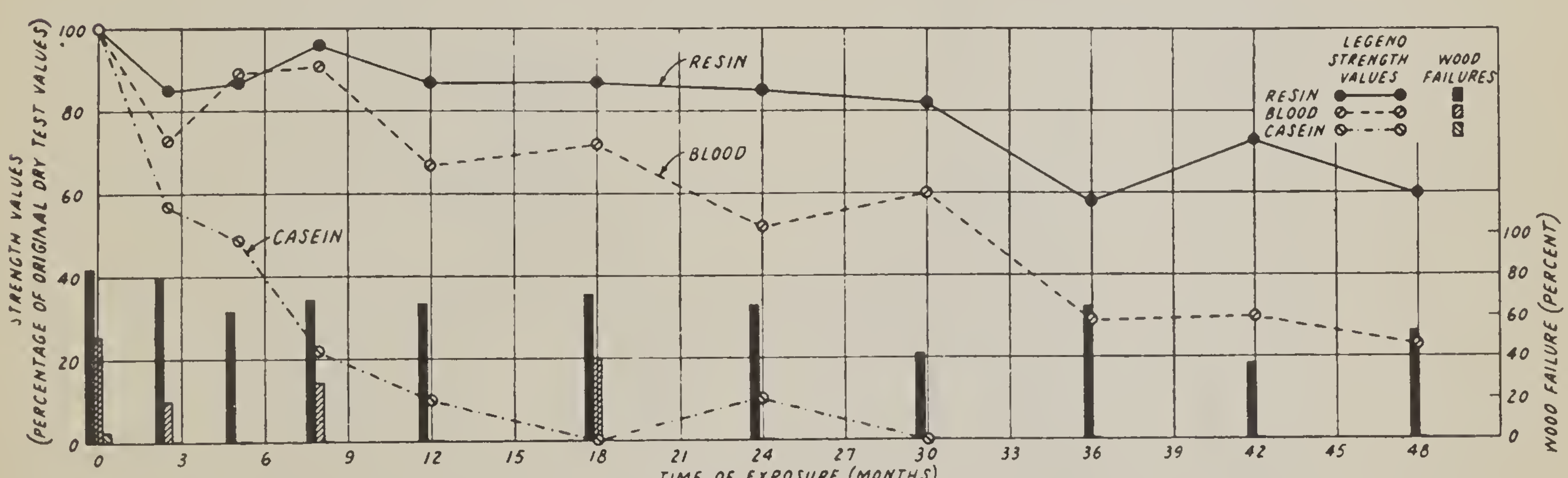


FIG. 3 RATE OF DETERIORATION OF GLUE JOINTS WHEN EXPOSED TO A REPEATING CYCLE OF 2 DAYS' SOAKING FOLLOWED BY 12 DAYS' DRYING

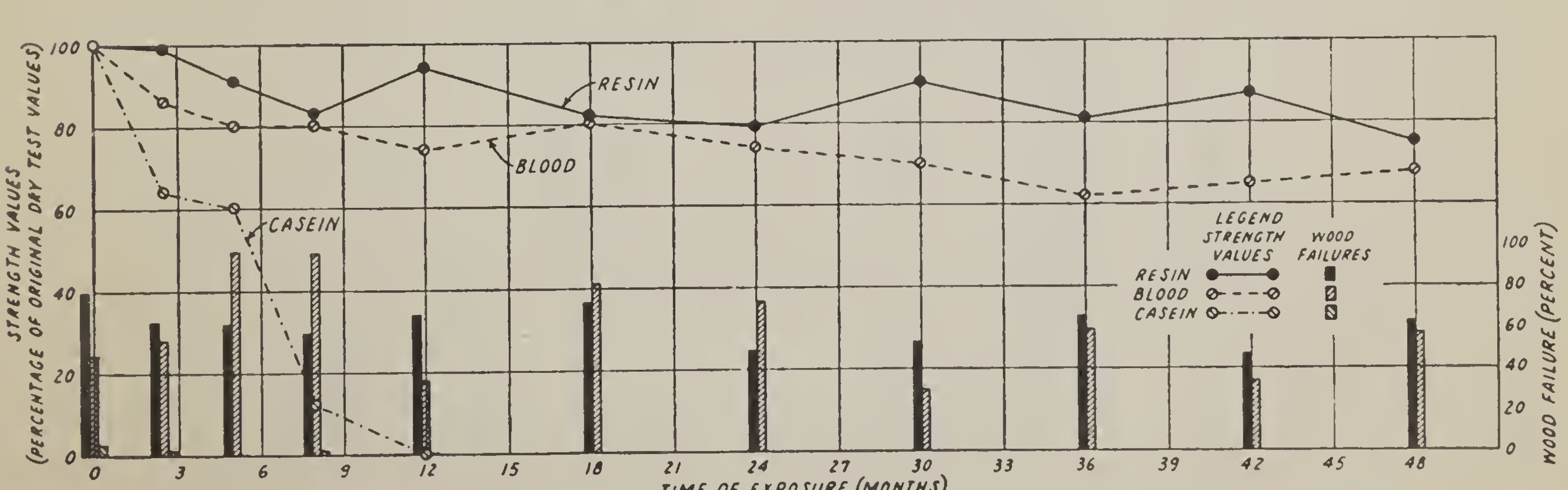
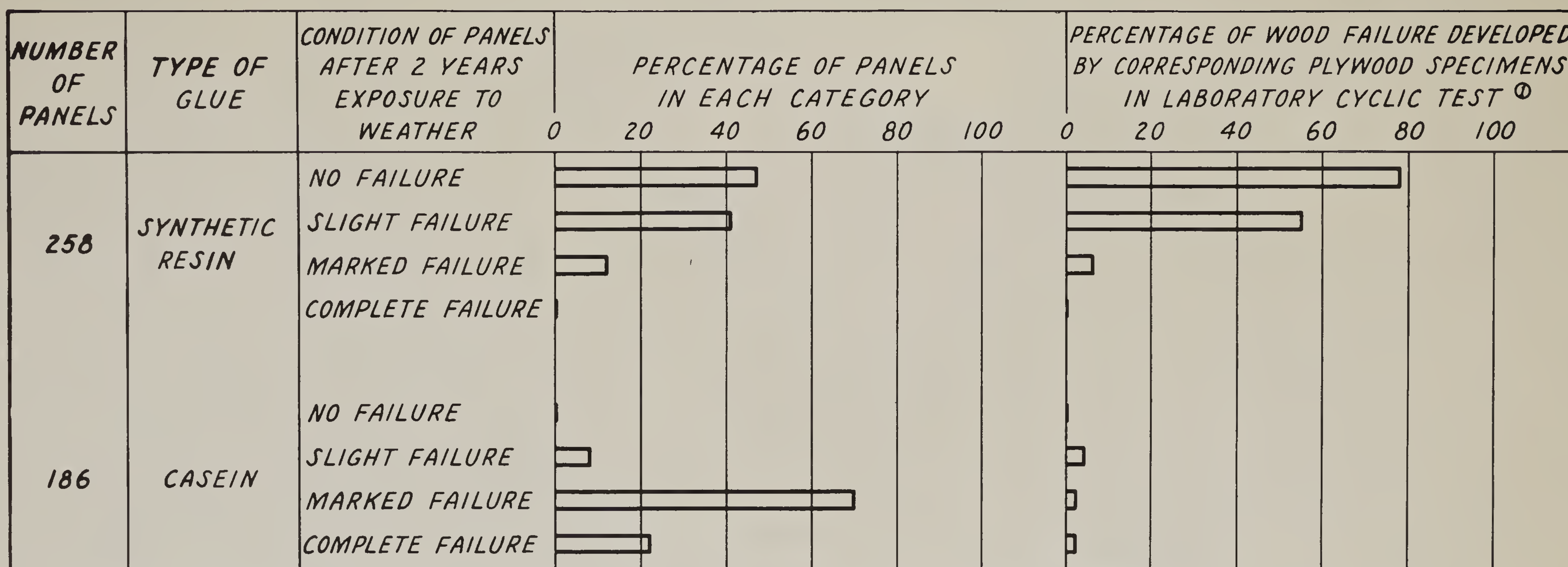


FIG. 4 RATE OF DETERIORATION OF GLUE JOINTS WHEN EXPOSED TO A REPEATING CYCLE OF 2 WEEKS IN 97 PER CENT RELATIVE HUMIDITY FOLLOWED BY 2 WEEKS IN 30 PER CENT RELATIVE HUMIDITY

Z M 34768 F



①—SPECIMENS WERE TESTED WET AFTER 3½ EXPOSURES TO A CYCLE THAT CONSISTED OF SOAKING IN WATER AT ROOM TEMPERATURES FOR 24 HOURS FOLLOWED BY DRYING AT 150°F. FOR 24 HOURS.

FIG. 5

RELATION BETWEEN DURABILITY OF GLUE JOINTS DURING 2 YEARS EXPOSURE TO WEATHER AND WOOD FAILURE IN CORRESPONDING PLYWOOD SPECIMENS WHEN TESTED AFTER EXPOSURE TO WETTING AND DRYING CYCLES

M 34871 F